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TESTS OF ROTORCHUTES

FRANZ J. A. HUBER
AIRCRAFT LABORATORY

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WRIGHT AIR DEVELOPMENT CENTER

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Franz J. A. Huber
Aircraft Laboratory

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Wind Tunnel Branch of the Aircraft Laboratory, Aeronautics Division, Wright Air Development Center. The test program was initiated at the request of the Physiology Branch, Aero Medical Laboratory and was carried out under Research and Development Order Number 696-81. The tests were conducted in the Wright Field 12-Foot Vertical Wind Tunnel, Wright Air Development Center, in connection with Quartermaster ration packaging contract with the Illinois Institute of Technology. Professor V. L. Streeter, Director of Fundamental Fluids Research, Department of Mechanics at Illinois Institute of Technology attended the tests and served as a technical advisor. Mr. Franz J. A. Huber is the project engineer.

ABSTRACT

Rotorchutes of 42 and 51 inches diameter with 2 and 4 untapered and untwisted blades with airfoil section were investigated in the Wright Field 12-Foot Vertical Wind Tunnel, WADC. In vertical descent and proper autorotation the rotorchutes had a drag coefficient referred to the rotor disc area of 1.0 to 1.3 and a tip speed ratio (circumferential speed to sinking speed) of 4.4 to 9.3. The maximum drag coefficient remained essentially constant between the largest blade incidence at which proper autorotation was possible and a blade incidence of about 6° less. When the blade incidence was decreased through this range the tip speed ratio increased about 40%. Changing from four blades (with a solidity of 18%) to two blades of the same chord, caused a slight increase in drag coefficient and a substantial increase in tip speed ratio. Blade offset forward seemed to slightly increase the drag coefficient. Blade sweep had no significant influence on the drag coefficient. Blade sweep forward and blade offset forward improved the starting of autorotation.

PUBLICATION REVIEW

This report has been reviewed and approved.

FOR THE COMMANDING GENERAL:

for D. D. McKEE
Colonel, USAF
Acting Chief, Aircraft Laboratory
Directorate of Laboratories

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LIST OF SYMBOLS

C_D	drag coefficient of rotorchute, $\frac{D}{\frac{\rho}{2} V^2 S}$
D	drag of rotorchute
S	rotor disc area as defined by end points of blade midchord line at 0° coning angle
V	sinking speed of rotorchute (wind tunnel speed)
V_T	circumferential speed of blade tips measured at end point of mid-chord line
V_T/V	tip speed ratio
ρ	air density

INTRODUCTION

Rotorchutes designed and constructed at the Illinois Institute of Technology were tested in the Wright Field 12-Foot Vertical Wind Tunnel at the request of the Physiology Branch, Aero Medical Laboratory, Wright Air Development Center.

A rotochute is an autorotating propeller used instead of a parachute to decrease the descent velocity of free falling loads.

The purpose of the rotorchute tests was to determine the influence of blade area, blade incidence, blade sweep, and blade offset on the drag, the tip speed, and the starting of autorotation.

SECTION I

GENERAL CONSIDERATIONS

The rotorchute is an autorotating propeller suggested for use instead of a parachute to decrease the descent velocity of free falling loads.

A rotorchute produces a high drag coefficient only when it imparts to the airflow a large momentum change in the axial direction. To obtain a drag coefficient larger than one, it is required, due to the law of momentum, that both the air flowing through and around the rotor disc be decelerated. This can be achieved with a rotorchute with a blade incidence angle close to the largest value at which autorotating is possible. Then the rotor will assume a rather high tip speed ratio and cause the flow at the outer parts of the blades to be deflected strongly outward, partly due to blockage and partly due to a centrifugal action of the blades. As a consequence, at the periphery of the rotor disc, a turbulent mixing zone is generated. In this mixing zone the airflow which passes outside of the rotor disc is also decelerated.

The rotorchutes tested were designed and constructed at the Illinois Institute of Technology, Department of Mechanics, Fundamental Fluids Research.

One rotorchute, the "Sitka Spruce Rotorchute", had four blades of sitka spruce and was about 42 inches in diameter. The blades had a constant chord of 3 inches and were square-cut at the tip. They were untwisted and of NACA 4412 Section. The blade hingeline was in a plane normal to the rotor axis. (For definition of rotor geometry, see Figure 1). It was possible to change:

1. The blade incidence between -4° and +4° (measured between tangent on pressure side of section and a plane normal to rotor axis).

2. The blade sweep between 0° and 10° forward (measured between hingeline normal and blade axis).

3. The blade offset between 0 and 1.5 inches forward (measured at the hingeline between the intersections with the hingeline normal through the rotor axis and the blade midchord line).

4. The rotor could be assembled with 2 and 4 blades.

To test this rotorchute with a smaller solidity, toward the end of the tests, two of the furnished blades were carved down to a chord of 2 inches and approximately a geometrically similar cross section. In addition, to investigate the effect of profile shape, two blades of 1/16 inch aluminum sheet metal with rounded leading and trailing edges, of the same length, 3 inch chord, and square cut tips were tested. The rotor diameter varied between 42.3 and 43.2 inches when the blade sweep and blade offset were changed through the above mentioned range.

The other rotorchutes, two "Balsa Wood Rotorchutes" each had two balsa wood blades. One rotorchute was 51 inches in diameter and its blades were offset 2 inches forward; the other was 50.75 inches in diameter and its blades were offset 2.5 inches forward. The blades of both rotorchutes had a constant chord of 5.5 inches and their tips were rounded in planview. The blade had an airfoil section, 7.3% thick with a flat pressure side. The blades had no twist and were installed at 0° incidence and 0° sweep. The blade hingeline was in a plane normal to the rotor axis. The solidity of these two rotorchutes was 0.134.

SECTION II

TEST EQUIPMENT AND PROCEDURE

The Wright Field 12-Foot Vertical Wind Tunnel, WADC, is an atmospheric pressure, annular return, closed circuit wind tunnel with an open test section 12 feet in diameter. The airflow in the test section is directed vertically upward at a velocity that is controlled by the wind tunnel operator.

The Sitka Spruce Rotorchute was tested as shown in Figure 3. The sheet metal aluminum blades were also tested on the hub of this rotorchute and in the same arrangement. The shaft of the rotor was mounted in a vertical guide in a cross beam above the wind tunnel nozzle lip. A slide was attached at the upper end of the shaft to prevent the rotor shaft from rotating. The rotor shaft was connected to a spring scale with a cable over a ball bearing mounted pulley. The friction surfaces of the vertical guide in the cross beam, on the thrust plate, and between the shaft and the rotor hub were frequently oiled to keep friction forces small.

When the rotor on the shaft was assembled in the desired configuration, the wind tunnel airflow was gradually turned on. While the speed of the airflow increased, the rotor was observed visually for its starting and accelerating behavior. When it rotated fast enough so that the blades were sufficiently stretched out by the centrifugal forces to prevent their striking the cross beam, the airflow velocity was increased to 46 ft/sec. Sufficient time was allowed for the steady state rotation to be established before any measurements were made. When it was judged that the rotor could withstand a higher airflow velocity, measurements were also made at 61 and 75 ft/sec. During the steady state rotation, a film record was made with a horizontally mounted moving picture camera.

The aerodynamic drag acting on the rotor was obtained by adding to the cable tension the weight of all parts on the cable above the pulley. The spring scale, which was used to measure the cable tension, was calibrated in the same horizontal position and with weights suspended over the same pulley. The sinking speed was obtained from the dynamic pressure in the test section and the air density. The rate of rotation of the rotor was determined with a stroboscope. The coning angle, when proper autorotation was established was found from the film to be of a small magnitude in these tests.

The two Balsa Wood Rotorchutes were actual flight test models and were not designed for testing on the cross beam. Therefore, they were tested as shown in the arrangement in Figure 4. Trials showed that the rotorchutes could not be tested in absolute free flight in the wind tunnel. The rotorchute with a load tied to its shaft was suspended in the center of the wind tunnel test section. Two guidelines strung across the test section were used to hold the rotorchute in the center region. The airflow was gradually turned on until the rotorchute with the load floated and the suspension line from above was loose. When the guidelines across the test section were practically without tension the measurements were made. The vertical force components of the guidelines on the rotorchute, if any, were ignored. Since the sinking speed was so small that the dynamic pressure could not be read directly with sufficient accuracy, it was obtained from the wind tunnel fan speed by assuming that the ratio of airflow velocity to rotational speed of the wind tunnel fan stayed in the same ratio as existed when the Sitka Spruce Rotor was tested at higher airflow velocities where the dynamic pressure and the fan speed were measured with sufficient accuracy. The rate of rotation was determined with a stroboscope.

The aerodynamic drag of the rotorchute including the load suspended underneath was equal to the total weight of rotorchute plus load. Because the drag of the load was small and because it would have been difficult to determine it accurately, only the total drag coefficient of rotorchute plus load was determined.

SECTION III

TEST RESULTS

A. General

The results of the rotorchute tests are presented in this section and in Figures 5 through 8. The presented drag coefficients and tip speed ratios are the values measured during the test without any correction applied. The data presented are estimated to be within the following limits:

Drag coefficient ±3% (except for 0.75 inch blade offset in Figure 6 where the accuracy was only ±10% because of partial jamming of the slide on top of the rotor shaft).

Tip speed ratio ±1%.

B. Sitka Spruce Rotorchute

The influence of blade incidence, blade sweep, blade offset, number of blades and solidity on the drag coefficient, the tip speed ratio, and the starting of proper autorotation with the Sitka Spruce Rotorchute was found to be as follows (Figures 5 through 8):

1. Drag Coefficient and Tip Speed Ratio

In vertical descent and proper autorotation, the drag coefficient of the rotorchute in the various tested configurations ranged from 1.0 to 1.3 and the tip speed ratio ranged from 4.4 to 9.3. The drag coefficient varied somewhat when the wind tunnel speed was changed. This is thought to be due to the change in Reynolds number and to the elastic twisting of the blades. Some of the drag coefficient curves are not smooth. The reason might be that the slide to prevent the rotor shaft from rotating could have jammed slightly. Because the curves of the tip speed ratio faired rather well, it may be assumed that the flow pattern and with it the drag coefficient of the rotor changed smoothly and not erratically. As the tip speed ratio did not change essentially when the tunnel speed was changed, an averaging curve was drawn for all airflow velocities.

2. Influence of Blade Setting

The maximum drag coefficient remained essentially constant between the largest angle of incidence at which proper autorotation was possible and an angle about 6° lower. When the blade incidence was decreased through that range, the tip speed ratio increased about 40%.

Blade sweep forward 5° and 10° had no significant influence on the drag coefficient or the tip speed ratio.

Blade offset forward 0.75 and 1.5 inches seemed to slightly increase the drag coefficient and the tip speed ratio.

3. Influence of Number of Blades and Solidity

Decreasing the number of blades from 4 to 2 and maintaining the same blade chord, i.e., reducing the solidity from 0.18 to 0.09 in most cases increased the drag coefficient somewhat and increased the tip speed ratio about 40%. Decreasing the solidity from 0.09 to 0.06 by reducing the blade chord of the two blade configuration caused the tip speed ratio to increase 20% but did not affect the drag coefficient.

4. Requirements for Proper Autorotation

When the airflow in the wind tunnel was turned on, the rotor-chute with the blades set at a proper angle of incidence started to rotate forward even though the blades were completely stalled out. As the rate of rotation increased, the angle of attack at the blades decreased and as soon as the flow attached at the outer parts of the blades the rotor accelerated rapidly till it reached its equilibruim condition where the resulting aerodynamic moment about the rotor axis acting at the rotor blades is zero. At this condition, the flow is attached over a large part of the blade length from the tip inward. At the outer part of the blades a decelerating force component is acting whereas, farther inward an accelerating force component acts on the blades. Close to the axis the angle of attack may still be so large that the section is stalled out.

In borderline cases, the rotor rotated at first, up to a minute or so, at relatively low speed with the flow at the blades obviously still separated and produced only a low drag. Then, rather suddenly, it increased its rotational speed by a factor of two or more due to the attachment of the flow at the outer part of the blades and the drag increased to the normal value for proper autorotation. When the angle of blade incidence was preset beyond a certain value, the rotor started to rotate backward. When a sufficiently large forward rotation was imparted to the rotor which started to rotate backward, the rotor assumed a proper forward autorotation when the blade incidence was not too large. The possibility of obtaining proper forward autorotation with high tip speed ratio increased with decreasing angle of blade incidence, because the angle of attack decreases with decreasing incidence and the more likely it is that attached flow will be produced at the leading edge of the blade.

Blade sweep forward and offset forward also improved the starting of proper autorotation because, due to the geometric relations, both decrease the angle of attack, especially at the large coning angles prevailing at low rotational speeds.

The data from the tests show that the possibilities of establishing proper autorotation are as follows:

When the blades were installed at zero sweep and zero offset, proper autorotation was still obtained with two and with four blades at zero degree blade incidence. With two blades, however, the rotor accelerated only slowly. When the blade incidence was increased to +2°, the rotor with two and with four blades could no longer be brought to proper autorotation.

Sweeping the blades 5° forward and maintaining zero blade offset had the effect that the rotor with four blades assumed proper autorotation still at +2° blade incidence but no more at +4° (two blades were not tested at these angles of incidence).

When the blades were installed with 10° sweep forward and with 0.75 inch offset forward, proper autorotation could be obtained up to +4° blade incidence with four blades and up to +2° blade incidence with two blades. With two blades and 4° blade incidence, proper autorotation could no longer be obtained.

5. Coning Angle

The coning angle of the blades when the rotor was in proper autorotation was very small, between two and four degrees. During the acceleration period the coning angle decreased from about 30° to the low values prevailing at proper autorotation.

6. Thin Sheet Metal Blades

With the two thin flat aluminum sheet metal blades installed with 5° sweep forward, with zero offset, and with zero incidence, the rotor did not accelerate to proper autorotation and produced a drag coefficient of only 0.36 at an airflow speed of 47 ft/sec. That the rotor with this blade setting did not accelerate to proper autorotation is not surprising when it is considered that the stalling angle of such a sheet metal blade is very low.

When the blade incidence was changed from 0° to -2°, the rotor obtained a tip speed ratio of 8.13 and produced a drag coefficient of 1.16. The airflow speed was 32 ft/sec and could not be increased because the blades started to flutter.

C. Balsa Wood Rotorchutes

The two Balsa Wood Rotorchutes, yielded the following results:

The rotorchute with 2 inch blade offset forward had a drag coefficient of approximately 1.3 and a tip speed ratio of 6.7 when thin nylon cords between shaft and the blades were installed. Removing the nylon cords did not noticeably change the drag coefficient but it did increase the tip speed ratio to 7.4.

The other rotorchute, which essentially differed from the above one only in that the blade offset forward was 2.5 inches instead of 2.0 inches, had a drag coefficient of approximately 1.1 and a tip speed ratio of 6.5.

The results obtained with the Sitka Spruce Rotorchute, which are thought to be more accurate, show an opposite influence of blade offset. The difference in drag coefficient and tip speed ratio of the two Balsa Wood Rotorchutes might be due to fabrication difference of the blades or inaccuracies in the measurements.

The above drag coefficients of the Balsa Wood Rotorchutes include the drag of the attached load, the cross sectional area of which was about 2% of the rotor disc area.

SUMMARY

In the Wright Field 12-Foot Vertical Wind Tunnel tests have been made with rotorchutes of 42 to 51 inches diameter to determine the drag, the tip speed, and the required blade setting to obtain autorotation.

In vertical descent and with proper autorotation, the rotorchutes had a drag coefficient of 1.0 to 1.3 and a tip speed of 4.5 to 9.3 times the sinking speed. The maximum drag coefficient remained essentially constant between the largest blade incidence at which proper autorotation was possible and a blade incidence of about 6° less.

The maximum obtainable drag coefficient did not vary essentially with a change in solidity over the tested range of solidity of 0.06 to 0.18 but the optimum solidity for obtaining a high drag coefficient seems to lie between 0.06 and 0.09.

Decreasing the blade incidence and sweeping and offsetting the blades forward were conducive to the establishment of proper autorotation.

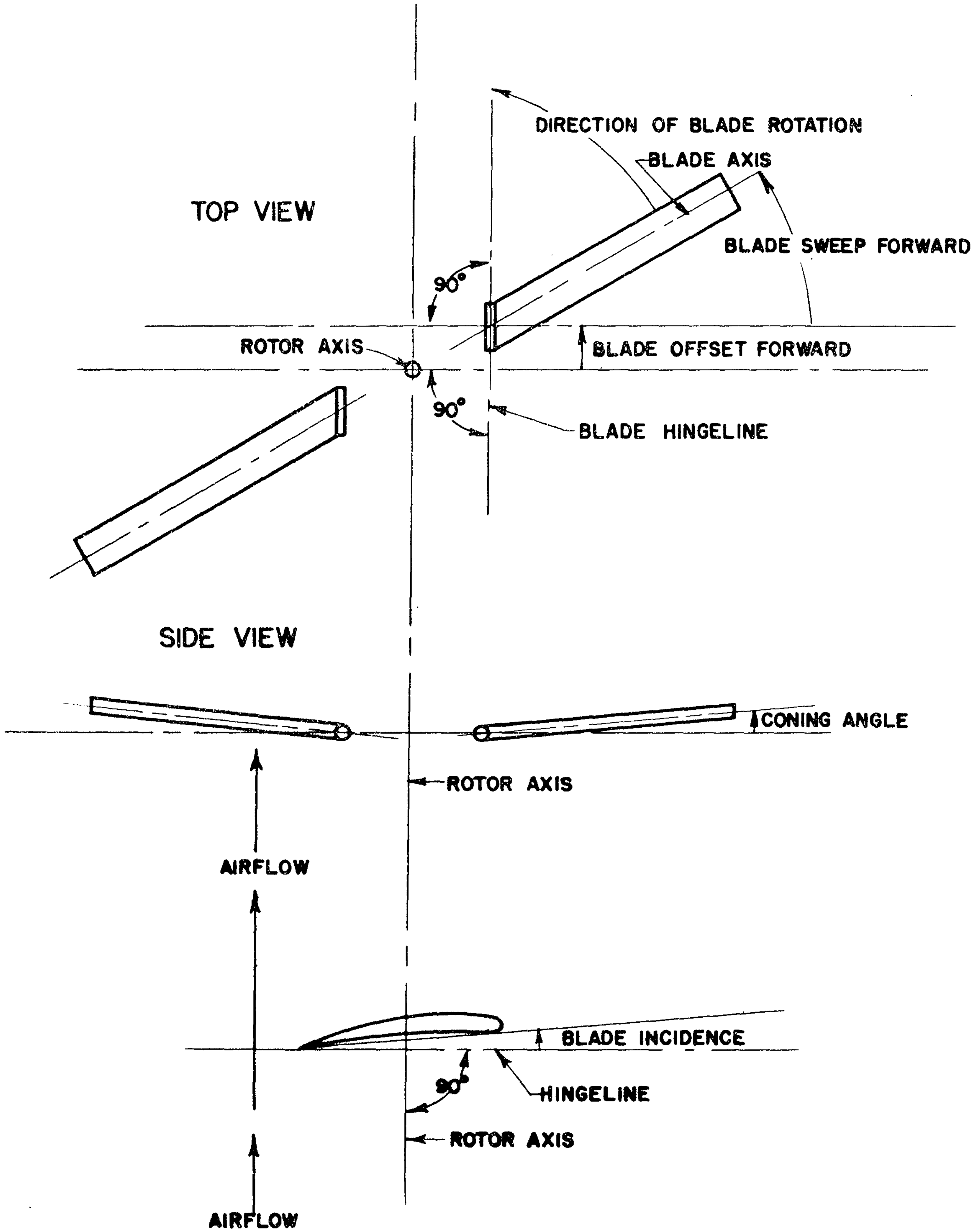

FIGURE 1: DEFINITION OF THE ROTOR GEOMETRY.

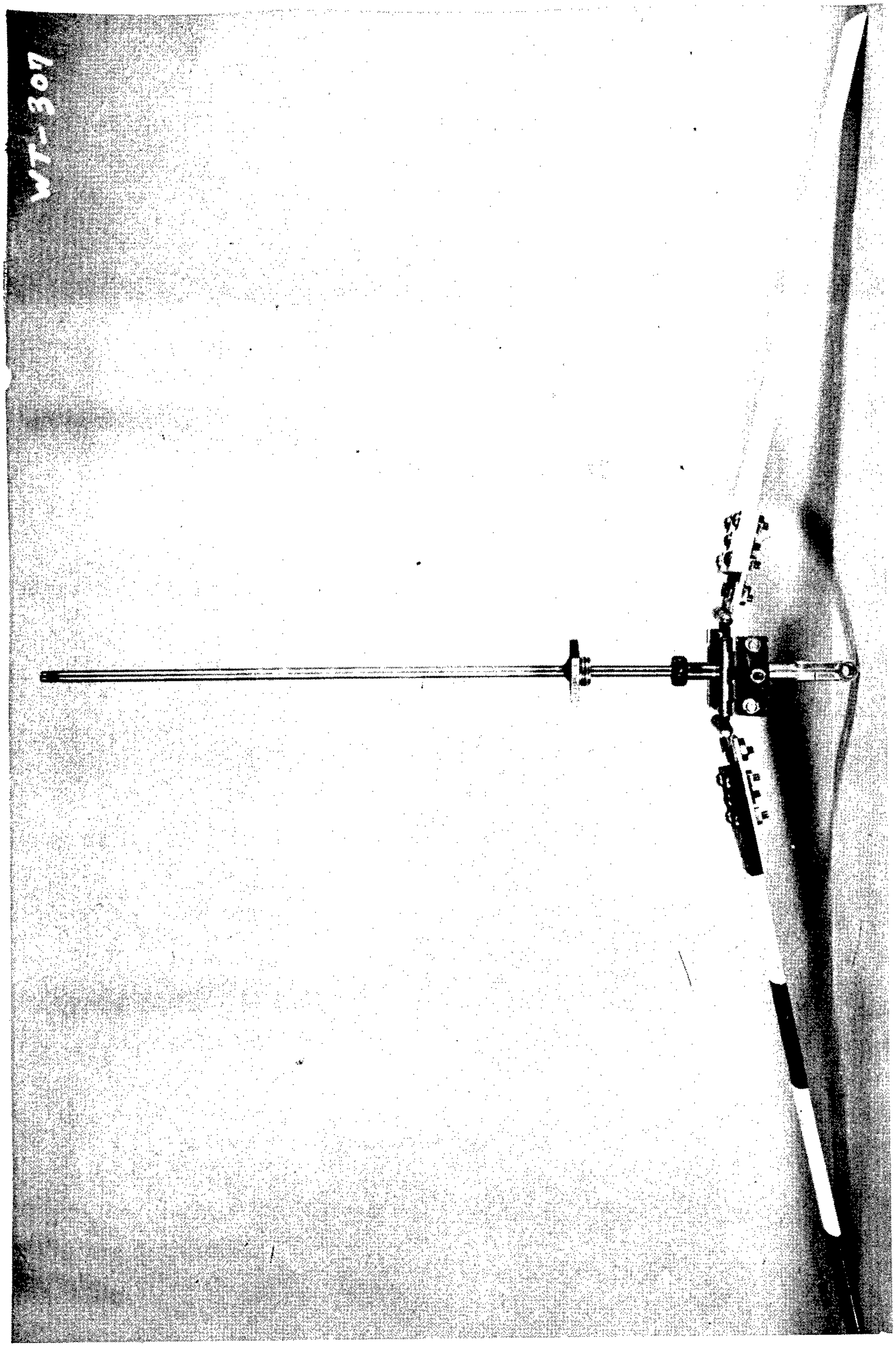

FIGURE 2: SITKA SPRUCE ROTORCHUTE, SIDE VIEW PHOTOGRAPH.

WRIGHT FIELD 12-FOOT VERTICAL WIND TUNNEL, WADC
TEST NUMBER 40

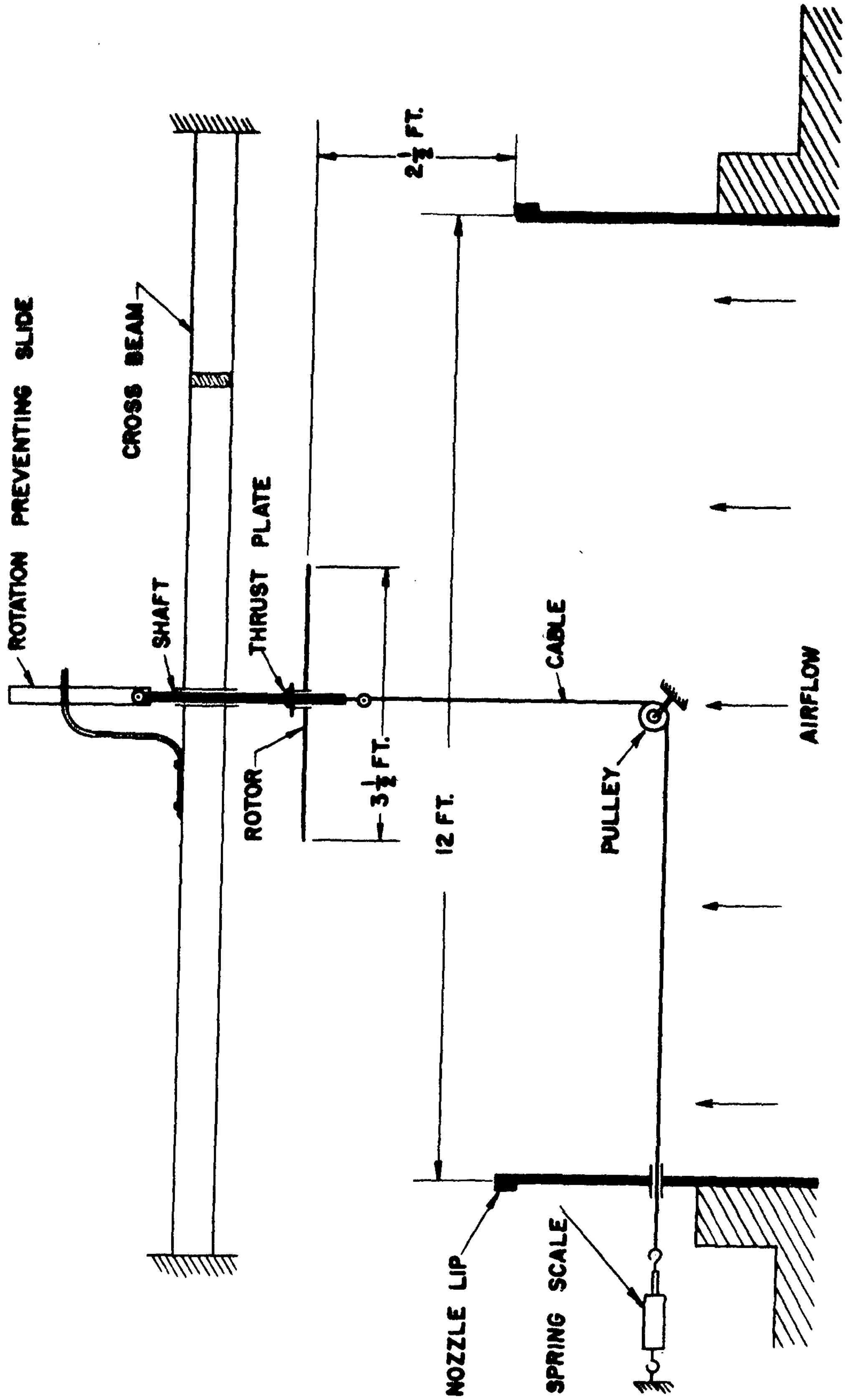

FIGURE 3: TEST ARRANGEMENT FOR THE SITKA SPRUCE ROTORCHUTE.

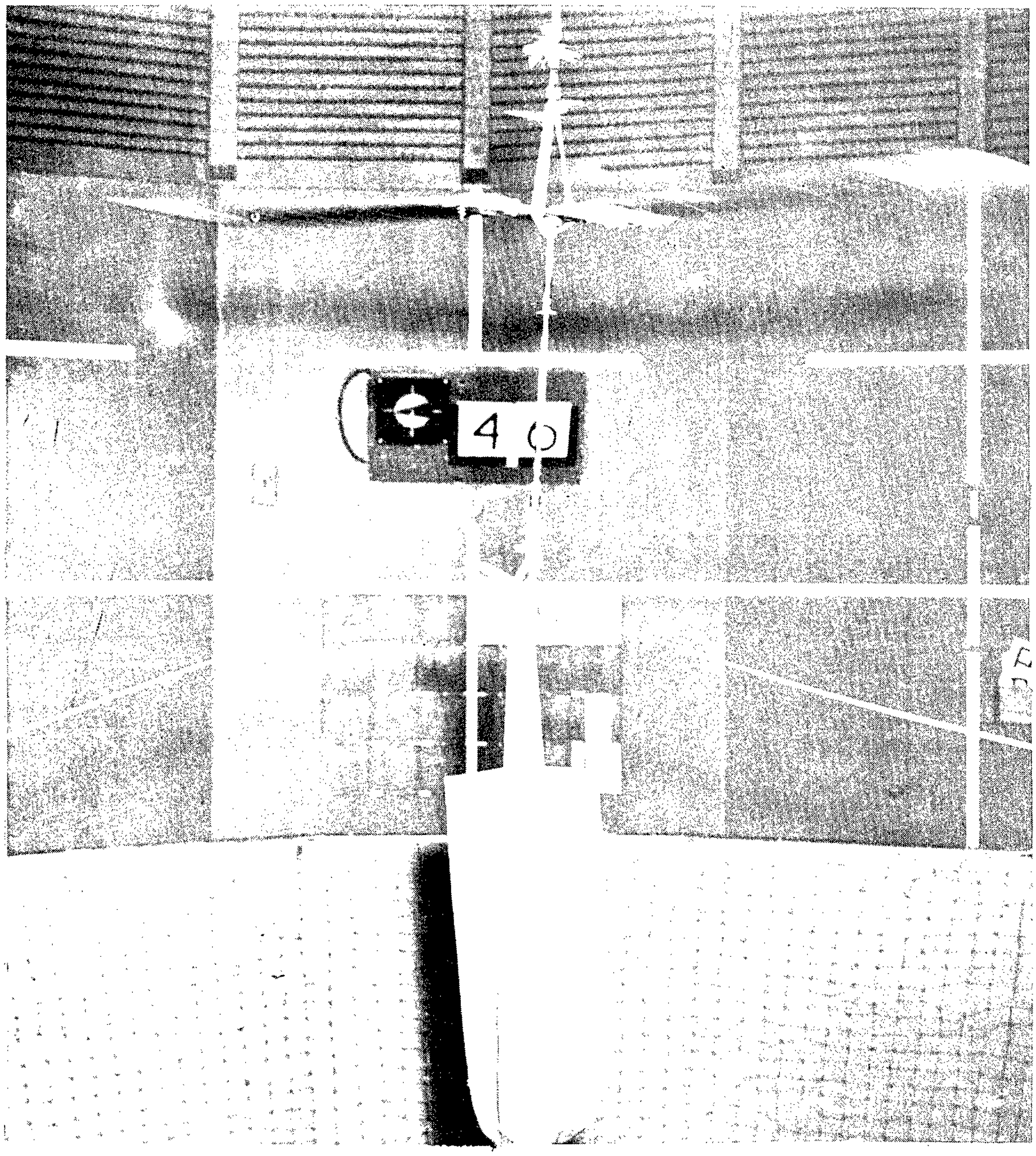

FIGURE 4: TEST ARRANGEMENT FOR THE BALSA WOOD ROTORCHUTE.

WRIGHT FIELD 12-FOOT VERTICAL WIND TUNNEL, WADC
TEST NUMBER 40

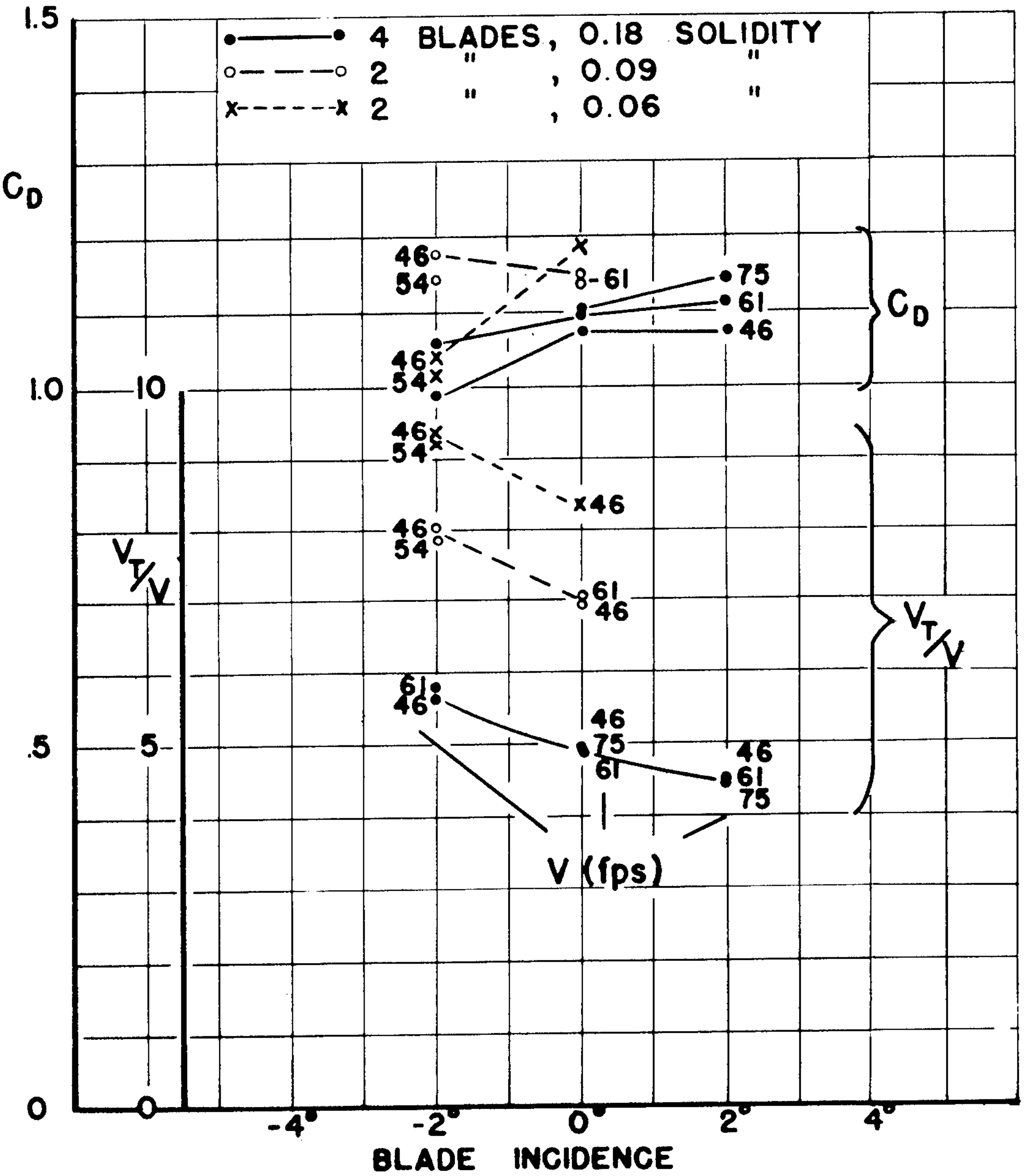

FIGURE 5: SITKA SPRUCE ROTORCHUTE, DRAG COEFFICIENT AND TIP SPEED RATIO WITH THREE DIFFERENT BLADE ARRANGEMENTS.